Final Report (June 1991)

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Title: IRAS Spectra of Carbon Stars

We have continued to analyze IRAS LRS spectra of carbon stars. The spectra were directly extracted from the LRS database supplied by the LRS team of University of Groningen. The extracted spectra are then corrected for baselines and mis-matching between the two bands. Flux calibration is obtained by convolving the spectra with the IRAS 12 μm instrumental profile, and set to the 12 μm survey flux. Relative calibration is obtained by using seven bright stars as standards. Evolved carbon stars are then selected based on the presence of the 11.3 μm SiC feature. In this process, we have discovered a number of mis-identification in the *IRAS LRS Atlas*, which for example, often mistakes the 10 μm silicate absorption feature as emission feature at 11.3 μm. At the end of the contract (June 1991), we have analyzed the LRS of 9631 sources (complete to $F_\nu(12\ \mu m)=8$ Jy), and 673 evolved carbon stars (defined as stars whose spectra show the SiC feature) have been identified. Most of these are new identifications.

A. Discovery of new carbon stars with silicate features and their identification as J stars

We have also correlated the extract spectra with the *General Catalogue of Cool Galactic Carbon Stars (2nd edition)* by Stephenson (1989, Publ. Warner and Swasey Obs. Vol. 3, no. 2). Out of the 5987 sources in GCCGCS, 3412 have associations with the IRAS Point Source Catalogue, and 532 of these have good LRS spectra. While a majority (412 out of 532) show the SiC feature, eleven show the 9.7 μm silicate feature in emission. The silicate feature is a characteristics of oxygen-rich stars, and is therefore not expected in carbon stars. We have obtained ground-based infrared photometry for some of these sources at CTIO, and have fitted the energy distribution of the objects with a radiative transfer model. The model results suggest that these stars were until recently M stars, but have since stopped its mass loss process. We were able to estimate the time since mass loss has stopped, as well as the mass loss rate when the star was an M star (Chan and Kwok 1991, *ApJ*, in press).

One of the most interesting development in this research is the identification of a number of J stars as possible transition objects between M and C stars. Evans (1990, *MNRAS*, 243, 336) has found that a number of the carbon stars with silicate features to be J stars, or stars that are rich in ^{13}C. While it is unclear why transition objects should be C^{13} rich, this discovery introduces a new insight into the origin of carbon stars. We have initiated a program of optical spectroscopy of these candidates. After 4 observing runs at the *Dominion Astrophysical Observatory*, we have been able to confirm that most of these candidates are indeed J stars.

B. Discovery of Extreme Carbon Stars

A number of extremely evolved carbon stars (i.e. those with very low color temperatures) were observed at United Kingdom Infrared Telescope in August, 1990. Photometry were obtained between 5 and 25 μm to define the overall energy distribution. We found that these sources have no optical counterparts down to V~20 mag. We were also able to determine accurate positions based on the 10 μm position of the stars. The infrared photometry data were fitted with radiative transfer models with optical depths at 11.3 μm ranging from 1.4 to 8 (or circumstellar extinction (A_v) ranging as high as 900). These results suggest that these stars have among the most optically thick circumstellar envelopes among all carbon stars observed to date. The identification of such evolved stars is important in the understanding of the last stages of carbon star evolution on the asymptotic giant branch.

Summary

Significant progress has been made both on the origin of carbon stars and the end of carbon star evolution. We were able to make productive use of the IRAS Low Resolution Spectra in the identification of transition objects from oxygen-rich to carbon stars, and in the identification of extremely evolved carbon stars. Both discoveries were followed up by ground-based observations. Specifically from optical spectroscopy we found that the newly-discovered transition objects are rich in C^{13}, which probably has important implications on the origin of carbon stars.

Publications directly resulted from this contract

Chan, S.J., & Kwok, S. *New Candidates for Carbon Stars with Silicate Features*, Astrophysical Journal, in press.

Volk, K., Kwok, S., & P. Langill *Candidates for Extreme Carbon Stars*, Astrophysical Journal, in press.

Chan, S.J., & Kwok, S. *J Stars as Transition Objects from M to C Stars*, in preparation.